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The undersigned declares further that all statements made herein of his/her own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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GaN single crystal substrate and manufacturing method thereof

[Claims]

1. A method for manufacturing a GaN single crystal substrate, characterized in that a plurality of GaN single crystal substrates are obtained by preparing a GaN single crystal ingot by epitaxially growing GaN, by a vapor-phase growth method, on a GaN single crystal as a seed crystal, and by slicing or cleaving the ingot.

2. The method for manufacturing a GaN single crystal substrate according to claim 1, characterized in that said seed crystal is a thin film of a GaN single crystal obtained by epitaxially growing GaN, by a vapor-phase growth method, on a GaAs substrate, and removing then the GaAs substrate.

3. The method for manufacturing a GaN single crystal substrate according to claim 1, characterized in that said seed crystal is a thin film of a GaN single crystal obtained by forming on a GaAs substrate a mask layer having a window, epitaxially growing GaN, by a vapor-phase growth method, on the mask, and then removing the GaAs substrate.

4. The method for manufacturing a GaN single crystal substrate according to claim 1, characterized in that said seed crystal is a thin film of a GaN single crystal obtained by forming on a GaAs substrate a mask layer having a window, and carrying out epitaxial growth on the mask layer by a vapor-phase growth method, and an ingot of said GaN single crystal is obtained by further continuing

vapor-phase growth of GaN on the thin film layer.

5. The method for manufacturing a GaN single crystal substrate according to claim 1, characterized in that said seed crystal is a GaN single crystal substrate obtained by slicing or cleaving an ingot of GaN single crystal.

6. The method for manufacturing a GaN single crystal substrate according to any of claims 2 to 4, characterized in that the plane on which said GaN is epitaxially grown on the GaAs substrate is the (111)A plane or the (111)B plane.

7. The method for manufacturing a GaN single crystal substrate according to any of claims 1 to 5, characterized in that the vapor-phase growth method of said GaN single crystal ingot is a HVPE method.

8. The method for manufacturing a GaN single crystal substrate according to any of claims 1 to 5, characterized in that the vapor-phase growth method of said GaN single crystal ingot is a metalorganic chloride vapor-phase growth method.

9. The method for manufacturing a GaN single crystal substrate according to any of claims 1 to 5, characterized in that the vapor-phase growth method of said GaN single crystal ingot is a MOCVD method.

10. The method for manufacturing a GaN single crystal substrate according to any of claims 1 to 5, characterized in that the vapor-phase growth method of said GaN single crystal ingot is a sublimation method.

11. The method for manufacturing a GaN single crystal substrate

according to any of claims 2 to 4, characterized in that the vapor-phase growth method of said GaN single crystal thin film is one method selected from the group consisting of a metalorganic chloride vapor-phase growth method, a MOCVD method and a HVPE method.

12. A GaN single crystal substrate characterized in that the n-type carrier concentration of a GaN single crystal substrate manufactured by the manufacturing method according to any of claims 1 to 5 is 1×10^{16} to 1×10^{20} cm^{-3}.

13. A GaN single crystal substrate characterized in that an electron mobility of a GaN single crystal substrate manufactured by the manufacturing method according to any of claims 1 to 5 is 80 to 800 cm^2/Vs.

14. A GaN single crystal substrate characterized in that a specific resistance of a GaN single crystal substrate manufactured by the manufacturing method according to any of claims 1 to 5 is 1×10^{-4} to 1×10 Ω cm.

15. The GaN single crystal substrate according to claim 12, characterized in that the thickness of a GaN single crystal substrate manufactured by the manufacturing method according to any of claims 1 to 5 is 0.07 to 1 mm.

[Detailed description of the invention]

[0001] [Field of the invention]

The present invention relates to a GaN single crystal substrate for use in light-emitting devices such as light-emitting diodes and/or semiconductor lasers using a III-V group nitride compound

semiconductor, and relates also to a method for manufacturing the same.

[0002] [Background art]

Most conventional light-emitting devices using nitride semiconductors have been employing sapphire substrates. Sapphire is an extremely stable substrate material, but, on the other hand, is also an extremely hard one that lacks cleavage planes, which increases costs during the dicing operation of a light-emitting diode, and prevents the formation of a reflective plane through cleavage in semiconductor lasers, thereby giving rise to quality problems and resulting higher costs.

[0003] The use of cleavable substrates such as SiC has been studied, with a view of solving the above problems; however, SiC substrates are expensive and problematic as regards supply, and hence are hardly suitable for mass production, in terms of cost.

[0004] Also, using such substrates is problematic in that the mismatch between the lattice constants between GaN and the substrate leads to the occurrence of numerous defects in the epi layer, such as dislocations and the like. Currently marketed GaN epi layers for devices are said to contain about $10^9/cm^2$ of dislocations. These defects are arguably one of the factors that determine the life of a semiconductor laser.

[0005] Under these circumstances, there have been recent reports on substantial reductions in the defect density of GaN single crystals by applying a stripe-like mask on sapphire and growing thereon a GaN thick film to promote lateral growth on the mask.

However, growth takes place on sapphire, with GaN still adhered to the sapphire substrate, and hence the above-described cleavage problem is not solved. A further problem is the difference in thermal expansion vis-à-vis that of sapphire, which gives rise to substrate warp, an undesirable occurrence in device manufacturing processes.

[0006] In light of the above, the most ideal substrates are GaN single crystals, but these are difficult to obtain in sizes large enough to allow them to be used as substrates. In the equilibrium state, they can be synthesized under extremely high pressure, but this is problematic in terms of achieving larger substrates, and hampers the realization of GaN single crystals on a commercial basis.

[0007] As a result of research on the above technical problems, the inventors had already proposed a method for lateral growth of GaN through a mask layer having a window (Japanese Patent Application Nos. H09-298300 and H10-9008). Specifically, this was a method for obtaining a GaN substrate by forming a striped and/or circular mask on a GaAs substrate, laterally growing GaN thereon, and then removing the GaAs substrate.

[0008] This method allows obtaining only one substrate per growth step, and is readily influenced by the substrate; accordingly, it would be desirable to achieve a high-quality GaN single crystal substrate at an even lower cost.

[0009] [Problems to be solved by the invention]

In the light of the above conventional problems, it is an object of the present invention to provide a GaN single crystal substrate and a manufacturing method thereof, such that the GaN single crystal

substrate comprises a GaN single substance the frequency whereof is easy to control, the GaN single crystal substrate being little influenced by the substrate for GaN growth, having few defects, no warp, and allowing reducing costs.

[0010] [Means for solving the problems]

The invention devised with a view of solving the above problems is a GaN single crystal substrate, and a manufacturing method thereof, characterized by obtaining a plurality of GaN single crystal substrates by using as a seed crystal a GaN single crystal substrate formed through a method of vapor-phase growth of GaN, or an already-existing GaN single crystal substrate, and carrying out thereon further vapor-phase growth, followed by thick-film formation, ingot formation, and slicing or cleaving of the ingot.

[0011] The seed crystal is obtained by growing GaN grown by a vapor-phase growth method on a GaAs substrate through epitaxial vapor-phase growth, followed by removal of the GaAs substrate to yield a single-substance GaN single crystal thin layer, this GaN single crystal thin layer then being used as a seed crystal.

[0012] Alternatively, a seed crystal can be obtained by forming on a GaAs substrate a mask layer having a window, growing then GaN on the mask layer, through epitaxial vapor-phase growth, and removing then the GaAs substrate to yield a single-substance GaN single crystal thin layer that is then used as a seed crystal.

[0013] Also, an ingot of GaN single crystal can be manufactured by forming on a GaAs substrate a mask layer having a window, growing then GaN on the mask layer, through epitaxial

vapor-phase growth, and, without removing the GaAs substrate, continuing then vapor-phase growth of GaN using the thin layer of GaN single crystal as a seed crystal.

[0014] The height of the ingot thickened with GaN single crystal by vapor-phase growth on a seed crystal is preferably at least 1 cm in terms of enabling effective mass production. GaN single crystal substrates are obtained then by slicing individual GaN sheets from the ingot, and by polishing the GaN slices. Since the substrates are thus manufactured through slicing or cleaving of an ingot, the substrates are remarkably free of warp.

[0015] Although there are various slicing methods for obtaining plural substrates from a GaN ingot, the cleavability of GaN single crystals can also be exploited herein, or a combination of slicing and cleaving.

[0016] One such GaN single crystal substrate obtained as described above can be used also as a seed crystal of the above ingot.

[0017] Vapor-phase growth methods include, for instance, HVPE (Hydride Vapor Phase Epitaxy), metalorganic vapor-phase growth, MOCVD, and sublimation. In actual growth, methods of HVPE, metalorganic vapor-phase growth and MOCVD are ordinarily employed up to the preparation of the seed crystal, while thick-film formation for manufacturing the ingot resorts to methods of HVPE method, metalorganic vapor-phase growth, MOCVD, and sublimation. Owing to fine-control difficulties, sublimation is suitable for thick-film formation, i.e. for ingot manufacturing.

[0018] In the HVPE method, metallic Ga and HCl gas react at

an upstream portion inside a hot wall-type reactor, to form GaCl, this GaCl reacting then with freshly circulating NH_3 gas in the vicinity of the substrate, to grow thereby GaN on the substrate.

[0019] In metalorganic vapor-phase growth, an organometal such as TMG (trimethyl gallium) or the like reacts with HCl gas at a high temperature inside a hot wall-type reactor, to form GaCl, this GaCl reacting then with NH_3 gas circulating in the vicinity of the substrate, to grow thereby GaN on the substrate.

[0020] In the MOCVD method, an organometal comprising Ga such as TMG or the like and NH_3 gas are blown together with a carrier gas onto a heated substrate, in a cold wall-type reactor, to grow thereby GaN on the substrate.

[0021] In a sublimation method, GaN powder, as a raw material, and a substrate are arranged opposing each other inside a reactor, and then evaporative diffusion of GaN is elicited through streaming of high-temperature NH_3 gas or the like, to grow thereby GaN on the substrate.

[0022] The GaAs (111)A plane and the (111)B plane are preferred during GaN growth on a GaAs substrate.

[0023] The GaN single crystal substrate obtained according to the present invention, without intentional doping, could be controlled to an n-type carrier concentration ranging from $1\times10^{16}cm^{-3}$ to $1\times10^{20}cm^{-3}$, an electron mobility ranging from 80 to 800 cm^2/Vs, and a specific resistance ranging from 1×10^{-4} to $1\times10\ \Omega$ cm.

[0024] The thickness of the GaN single crystal substrate ranges from 0.07 mm to 1 mm. At 0.07 mm or above, the single crystal

substrates sliced or cleaved from an ingot can be obtained without single crystal substrate damage, the substrates having a strength that permits handling during device manufacture. Beyond 1 mm, the single crystal substrates sliced or cleaved from an ingot are few in number, which is undesirable in economic terms.

[0025] [Embodiments of the invention]

(Example 1)

Fig. 1 illustrates schematically cross sections in Example 1 over various processes. As illustrated in (a) of Fig. 1 a 2 inch-thick GaAs substrate (111) A plane was used herein as the substrate. An insulating thin film comprising SiO_2 was formed on the GaAs substrate (1), after which a mask layer (2) having striped windows was formed by photolithography extending in the <11-2> direction and having a window width of 3 μm and a mask width of 5 μm, as illustrated in (b) of Fig. 1.

[0026] Thereafter, 70 nm of a buffer layer comprising GaN were formed by HVPE at a low temperature of about 500°C, followed by a rise in temperature to a high temperature of 1000°C, to grow a GaN epitaxial layer (3) about 25 μm thick, as illustrated in (c) of Fig. 1. The orientation of the stripe mask coincides with the <1-100> direction of the GaN.

[0027] HVPE in the present example involved, as illustrated in Fig. 3, a Ga metal (6) boat inside a reactor at normal pressure, with HCl gas streamed over the boat heated at 800°C or more, to synthesize GaCl; thereafter, the GaCl is made to react with NH_3 gas in the vicinity of a substrate (8), to grow GaN on the substrate. H_2

was used as the carrier gas in all instances.

[0028] After removing the GaN film from the reactor and verifying that the GaN film was made into a mirror-surface continuous GaN film, the GaAs substrate was removed by etching in aqua regia, to yield the GaN thin layer plate illustrated in (d) of Fig. 1. After thorough washing, the GaN thin layer plate was set again in the HVPE reactor, to grow a GaN thick film, as illustrated in (e) of Fig. 1, on the obtained GaN thin film plate, by HVPE at a high growth temperature of 1020°C, yielding eventually a GaN single crystal ingot (4). The obtained ingot, which sagged slightly in the central portion, had a lowest height of about 2 cm and an outer diameter of 55 mm.

[0029] Thereafter, the ingot was sliced using an inner-tooth slicer, to yield 20 GaN single crystal substrates having an outer diameter of about 50 mm and a thickness of 350 μm. The substrates were lapped and finished through polishing, to yield GaN single crystal substrates (5) such as the one illustrated in Fig. 1(f), as finished products. Thanks to such a mechanical processing, the substrates suffered no noticeable warp.

[0030] In the conventional manufacturing method already carried out by the inventors in Japanese Patent Application Nos. H09-298300 and H10-90008, where a GaN single crystal substrate is obtained by laterally growing GaN via a mask layer having a window, one growth step yields only one single crystal substrate; in the present example, by contrast, there are obtained 20 substrates in one step. Manufacturing costs, therefore, sank to 65% of the lowest

costs achievable by conventional methods. Costs were thus reduced considerably, while the manufacturing time per substrate, including quality control, was shrunk.

[0031] The results of electric characteristic measurements carried out on the GaN single crystal substrates obtained from the uppermost portion of the ingot yielded an n-type carrier concentration of 5×10^{18} cm^{-3}, an electron mobility of 200 cm^2/Vs, and a specific resistance of 0.017 Ω cm.

[0032] The results of electric characteristic measurements carried out on the GaN single crystal substrate obtained from the lowermost portion of the ingot yielded an n-type carrier concentration of $8\times10^{18}cm^{-3}$, an electron mobility of 150 cm^2/Vs, and a specific resistance of 0.010 Ω cm.

[0033] Accordingly, the characteristics in the middle of the ingot, for quality control purposes, vary between these values or are close to them, and there is thus no need to inspect all the substrates.

[0034] LEDs having an InGaN light-emitting layer were manufactured using these GaN substrates; these LEDs exhibited a light emission luminance about five times greater than that of conventional LEDs formed on sapphire. This increase in light emission luminance is arguably derived from the absence of through-dislocations in the active layer of the LEDs of the present embodiment, as compared with the active layer of conventional LEDs, where such through-dislocations are plentiful.

[0035] (Example 2)

After forming a mask layer comprising SiO_2 on the (111) B

plane of a GaAs substrate, striped windows were formed extending in the <1-10> direction. Thereafter, 80 nm of a buffer layer comprising GaN were formed by organometal vapor-phase growth at a low temperature of about 490°C, then a 25 μm epitaxial layer of GaN was grown at 970°C, to yield thereby a mirror-surface GaN single crystal substrate on the GaAs substrate. The orientation of the stripe mask coincides with the <11-20> direction of the GaN.

[0036] Herein, GaN was grown by organometal vapor-phase growth using the apparatus illustrated in Fig. 4, in which TMG infused at 1×10^{-2} atm and HCl gas infused at 1×10^{-2} atm were made to react with each other inside a reactor having an inner temperature of 850°C, under normal pressure, and wherein NH_3 gas was streamed in the vicinity of the substrate. H_2 was used as the carrier gas in all instances. The substrate temperature was of 490°C during growth of the buffer layer, and 970°C during epitaxial growth.

[0037] Next, the GaAs substrate was removed by etching in aqua regia, after which the GaN thin film plate was thickened by HVPE at a growth temperature of 1000°C, to manufacture an ingot. The obtained ingot, which sagged slightly in the central portion, had a lowest height of about 3 cm.

[0038] Thereafter, the ingot was sliced using an inner-tooth slicer, to yield 25 GaN single crystal substrates having a thickness of 400 μm. The substrates were lapped and finished through polishing, to yield GaN single crystal substrates as finished products.

[0039] The results of electric characteristic measurements yielded an n-type carrier concentration of 2×10^{18} cm^{-3}, an electron

mobility of 250 cm^2/Vs, and a specific resistance of 0.05 Ω cm.

[0040] In a conventional manufacturing method, where a GaN single crystal substrate is obtained by laterally growing GaN via a mask layer having a window, one growth step yields only one single crystal substrate; in the present example, by contrast, there are obtained 25 substrates in one step. Manufacturing costs, therefore, sank to 65% of the lowest costs achievable by conventional methods. Costs were thus reduced considerably, while the manufacturing time per substrate, including quality control, was shrunk.

[0041] Besides the striped windows, various other mask window shapes, such as a dot shape and the like, are also possible; herein, all these shapes are useful in decreasing internal stress during removal of the GaAs substrate and in reducing warp. This is due to the reduction in dislocations through lateral growth on the mask.

[0042] (Example 3)

Fig. 2 illustrates schematically cross sections in Example 3 over various processes. As illustrated in (a) of Fig. 2, a GaAs substrate (111) A plane was used herein as the substrate. An insulating thin film comprising SiO_2 was formed on the GaAs substrate (1), after which a mask layer (2) having striped windows was formed by photolithography extending in the <11-2> direction and having a window width of 3 μm and a mask width of 5 μm, as illustrated in (b) of Fig. 2.

[0043] Thereafter, 90 nm of a buffer layer comprising GaN were formed by HVPE at a low temperature of about 500°C, followed by a rise in temperature to a high temperature of 1000°C, to

grow a GaN epitaxial layer. The orientation of the stripe mask coincides with the <1-100> direction of the GaN.

[0044] Unlike in Example 1 and Example 2, the GaN single crystal ingot (4) was manufactured in a single step, as illustrated in (c) of Fig. 2. The method of Example 2 affords thus a greater cost reduction than Example 1, since the process can be shrunk further. The ingot, which sagged slightly in the central portion, had a lowest height of about 1.6 cm.

[0045] Thereafter, the ingot was sliced using an inner-tooth slicer, to yield 12 GaN single crystal substrates having a thickness of 300 μm. The substrates were lapped and finished through polishing, to yield GaN single crystal substrates (5), such as the one illustrated in (d) of Fig. 2, as finished products.

[0046] In a conventional manufacturing method, where a GaN single crystal substrate is obtained by laterally growing GaN via a mask layer having a window, one growth step yields only one single crystal substrate; in the present example, by contrast, there are obtained 12 substrates in one step. Manufacturing costs, therefore, sank to 60% of the lowest costs achievable by conventional methods. Costs were thus reduced considerably, while the manufacturing time per substrate, including quality control, was shrunk.

[0047] The results of electric characteristic measurements yielded an n-type carrier concentration of 7×10^{18} cm^{-3}, an electron mobility of 170 cm^2/Vs, and a specific resistance of 0.01 Ω cm.

[0048] (Example 4)

A case was also considered in which no mask was used;

although cracks developed on account of large resistance and internal stresses, a relatively good ingot can be obtained depending on the growth conditions.

[0049] Then, 90 nm of a buffer layer comprising GaN were formed by HVPE, at a low temperature of about 500°C, on the (111) B plane of a GaAs substrate, followed by a rise in temperature to a high temperature of 1030°C, to simultaneously grow a GaN epitaxial layer and manufacture a GaN single crystal ingot. The ingot, which sagged slightly in the central portion, had a lowest height of about 1.2 cm.

[0050] Thereafter, the ingot was sliced using an inner-tooth slicer, to yield 10 GaN single crystal substrates having a thickness of 300 μm. The substrates were lapped and finished through polishing, to yield GaN single crystal substrates as finished products.

[0051] In a conventional manufacturing method, where a GaN single crystal substrate is obtained by laterally growing GaN via a mask layer having a window, one growth step yields only one single crystal substrate; in the present example, by contrast, there are obtained 10 substrates in one step. Manufacturing costs, therefore, sank to 70% of the lowest costs achievable by conventional methods. Costs were thus reduced considerably, while the manufacturing time per substrate, including quality control, was shrunk.

[0052] The results of electric characteristic measurements yielded an n-type carrier concentration of 1×10^{19} cm^{-3}, an electron mobility of 100 cm^2/Vs, and a specific resistance of 0.005 Ω cm.

[0053] (Example 5)

Further GaN single crystal ingots can be manufactured using as seed crystals the GaN single crystal substrates prepared in accordance with the methods of Examples 1 through 4. The present method is the simplest manufacturing method.

[0054] A GaN single crystal ingot was prepared by forming a GaN thick film on the GaN single crystal substrate obtained in Example 1, having an outer diameter of 50 mm, through HVPE at a growth temperature of 1010°C. The obtained ingot, which sagged slightly in the central portion, had a lowest height of about 2.5 cm and an outer diameter of 55 mm.

[0055] Thereafter, the ingot was sliced using an inner-tooth slicer, to yield 15 GaN single crystal substrates having an outer diameter of about 50 mm and a thickness of 600 μm. The substrates were lapped and finished through polishing, to yield GaN single crystal substrates as finished products.

[0056] In a conventional manufacturing method, where a GaN single crystal substrate is obtained by laterally growing GaN via a mask layer having a window, one growth step yields only one single crystal substrate; in the present example, by contrast, there are obtained 15 substrates in one step. Manufacturing costs, therefore, sank to 55% of the lowest costs achievable by conventional methods. Costs were thus reduced considerably, while the manufacturing time per substrate, including quality control, was shrunk.

[0057] The results of electric characteristic measurements yielded an n-type carrier concentration of $1x10^{17}$ cm^{-3}, an electron mobility of 650 cm^2/Vs, and a specific resistance of 0.08 Ω cm.

[0058] (Example 6)

A GaN single crystal ingot was prepared by forming a GaN thick film on the GaN single crystal substrate obtained in Example 2, having an outer diameter of 35 mm, through sublimation at a growth temperature of 1200°C.

[0059] In sublimation growth, GaN was grown by arranging a GaN substrate opposite the surface of GaN powder, inside a reactor, and by streaming 200 sccm of NH_3, with N_2 as a carrier gas, at a growth temperature of 1050°C.

[0060] The obtained ingot was relatively flat, and had a height of about 0.9 cm and an outer diameter of 35 mm. Thereafter, the ingot was sliced using an inner-tooth slicer, to yield 5 GaN single crystal substrates having an outer diameter of about 35 mm and a thickness of 500 μm. The substrates were lapped and finished through polishing, to yield GaN single crystal substrates as finished products.

[0061] In a conventional manufacturing method, where a GaN single crystal substrate is obtained by laterally growing GaN via a mask layer having a window, one growth step yields only one single crystal substrate; in the present example, by contrast, there are obtained 5 substrates in one step. Manufacturing costs, therefore, sank to 80% of the lowest costs achievable by conventional methods. Costs were thus reduced considerably, while the manufacturing time per substrate, including quality control, was shrunk.

[0062] The results of electric characteristic measurements yielded an n-type carrier concentration of $1x10^{18}$ cm^{-3}, an electron

mobility of 200 cm^2/Vs, and a specific resistance of 0.03 Ω cm.

[0063] [Effect of the invention]

The invention has the effect of allowing manufacturing a warp-free, high-quality GaN single crystal substrate at a low cost and in a short time.

[Brief description of the drawings]

Fig. 1 is a diagram illustrating schematically cross sections in Example 1 over various processes.

Fig. 2 is a diagram illustrating schematically cross sections in Example 3 over various processes.

Fig. 3 is a diagram illustrating schematically an HVPE apparatus in Examples 1 through 5.

Fig. 4 is a diagram illustrating schematically a metalorganic vapor-phase growth apparatus in Example 2.

[Description of the reference numerals]

1. GaAs
2. Mask
3. GaN
4. GaN ingot
5. GaN substrate
6. Ga metal
7. Heater
8. Substrate

Fig. 1

2 MASK

4 GaN INGOT

5 GaN SUBSTRATE

Fig. 2

2 MASK

4 GaN INGOT

5 GaN SUBSTRATE

Fig. 3

6 Ga METAL

7 HEATER

8 SUBSTRATE

EXHAUST GAS

FIG. 4

7 HEATER

8 SUBSTRATE

EXHAUST GAS

[Document name] Abstract

[Abstract]

[Problem] When obtaining a GaN substrate, a method of forming a GaN thin film on a GaAs substrate and then removing the GaAs substrate is expensive since only one substrate can be obtained per growth step and also the GaN substrate is easily influenced by the GaAs substrate, hence warp-free, high-quality GaN single crystal substrates cannot be obtained.

[Solution] A plurality of single crystal substrates can be obtained by manufacturing a GaN thick film ingot by a vapor-phase growth method, using a GaN single crystal as a seed crystal, and by slicing or cleaving the ingot.

[Selected drawing] Fig. 1